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Procedia Computer Science 42 (2014) 46 – 53

Procedia Computer Science

International Conference on Robot PRIDE 2013-2014 - Medical and Rehabilitation Robotics and Instrumentation, ConfPRIDE 2013-2014

Development of Shoe Attachment Unit for Rehabilitation Monitoring

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Abstract

The rehabilitation monitoring is a method to access and identify human body events and the measurements of dynamic and motion parameters involving the lower part of the body. This significant method is widely used in rehabilitation, sports and health diagnostic towards improving the quality of life. Thus, this research focuses on the development of a portable shoe integrated with wireless MEMS-based and recent microelectronic based system. It goes with the custom design package includes ultrasonic sensor, Inertia Measurement Unit (IMU), Xbee wireless signal transmission, microcontroller and power supply unit. The shoe system was tested and proven to satisfy the human movement analysis based on gait parameters which include foot clearance and foot orientation. From this research, it is found that the system was able to measure the movement parameter wirelessly with ease and efficient. Hence, to conclude this system can be used as the best method for real life rehabilitation monitoring system.

Peer-review under responsibility of the Center for Humanoid Robots and Bio-Sensing (HuRoBs)

Keywords: Rehabilitation Monitoring; Gait Analysis; Arduino; Xbee

1. Introduction

Healthcare cost continues to increase globally partly due to the surge in the occurrence of falls among the human being. The important gait parameter that influences the risk of falling among the human is foot clearance. The foot-ground reaction forces of produced by human body in is very important in gait analysis [1]. It is the natural parameter of the foot during the swing phase of the gait cycle that representing the distance of shoe sole above the ground. In a recent study involving the analysis of the tripping and falling risks among the elderly and individuals during walking [2], it is found that the motion of the foot during mid-swing phase is the most critical issue that can initiate the possibility of trip-related decline. The trip or fall is an event which may lead someone to collapse

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doi:10.1016/j.procs.2014.11.032

accidently due to unstable position. It is a very dangerous incident among the elderly as it may cause critical injury and death [3]. This important stage of foot movement is referred to as minimum foot clearance (MFC). Previous study in [4] shows the MFC is below than 5 cm while the foot trajectory during gait may go up to 17 cm. Unluckily, the current practice of measuring foot clearance mostly requires laboratory settings with the use of reflective and active markers. This type of foot clearance measurement may not be representative of real life based measurement in natural settings [5], such as at home or outdoors. Based on such fall prediction systems, response from caregivers may be triggered prior to most fall occurrences and accordingly prevent falls from taking place [6]. Therefore, this research is focussed on the wireless and portable shoe integrated clearance sensor system for rehabilitation monitoring system.

Nomenclature

v	velocity (m/s)
s	distance (m)
t	time (s)
l	length (m)
tof	time of flight (s)

2. System Configuration

The selections of sensors and hardware are depending on the requirement of the foot clearance measurement. The sensors that are used in this research are ultrasonic sensor and IMU for determination of the MFC as well as the orientation of foot position respectively. The monitoring system is not complete without other additional components that support the key functionality of the entire system. The hardware design consists of Arduino microcontroller, 2.4 GHz IEEE 802.15.4 XBee transceiver and power supply unit. This research used the Arduino compatible board named ArduIMU V2 Flat as processing unit which incorporated the Micro-Electro-Mechanical-System (MEMS) based IMU sensor on a single board.

2.1 Ultrasonic Sensor

Ultrasonic detectors are devices that are utilized for distance measurement which operates almost similar to how the radar is working where the distance is deduced from the total time of flight of the signal waves and the signal speed. Some ultrasonic device can transmit and receive high frequency sound waves using a single device which is also called as a transceiver. Table 1 below shows the specification of the selected ultrasonic sensor in the market for MFC measurement application and the principle of an ultrasonic sensor is shown in Fig 1.

Table 1. Specification of Ultrasonic Sensors for Minimum Foot Clearance Measurement Application

Model/ Specification	SRF05 (Devantech Ltd, 2012)
Power (V)	5
Frequency (kHz)	40
Resolution	1mm
Range	1cm-4m
Unit	Mm, cm, inch, m
Interface	Positive TTL level signal, width proportional to range
Weight	9g
Dimension (mm)	43 W x 20 D x 17 H
Manufacturer	Devantech Ltd, England

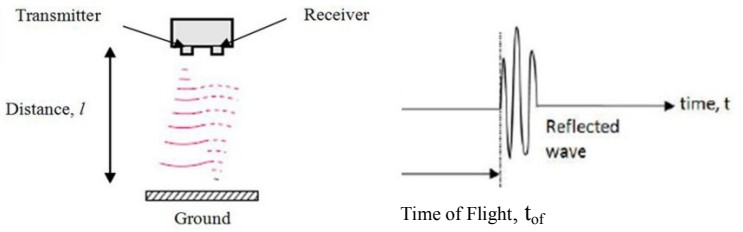


Fig 1. A Simple Time of Flight Concept [5]

An accurate distance can be obtained by measuring the time of flight (t_{of}) value of the ultrasonic signal as stated in [7]. In using of t_{of} method, after an ultrasound signal is transmitted by a transmitting transducer (transmitter), the distance, *l*, can be calculated based on the time t, taken by the ultrasound echo to return to the receiver [8]. Equation (1) and (2) represent the distance, and the velocity, v, equation respectively.

$$l = \frac{c(tof)}{2} \tag{1}$$

$$v = \frac{s}{t} \tag{2}$$

2.2 Inertial Measurement Unit

An inertial measurement unit (IMU) is a device that contains accelerometer and gyroscope used to measure angular rate and acceleration data. The IMU also used in spacecraft, watercraft and guided missile for the navigation system purpose [9]. This research takes advantage such advanced technology as an orientation sensor in gait motion field. It can be used as well in rehabilitation and sport training. Fig 2 shows the orientation of the IMU sensor incorporated into a shoe integrated system. Instead of orientation, the IMU was used for error correction algorithm in foot clearance measurement. This error exists when the ultrasonic is not parallel to the reference surface which resulted in the distance measured to be not an actual foot clearance value. The situation is explained graphically in Fig 3 (a) and Fig 3 (b) below.

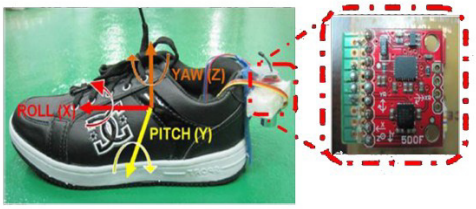
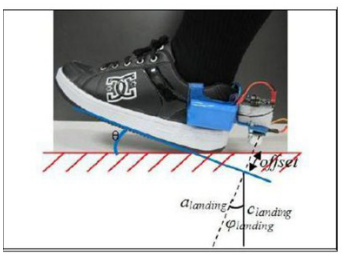


Fig 2. Orientation of IMU Sensor On Top of Portable Shoe Integrated (Left);
IMU Sensor Module (Right)

(a)



(b)

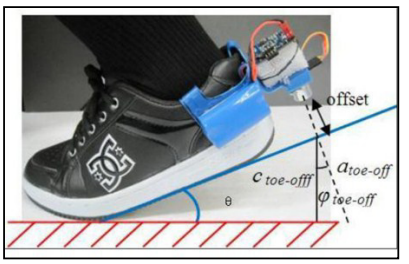


Fig 3. Foot Angle (θ) (a) During Landing Phase; (b) During Toe-Off Phase
Where the Distance Measured Is Not the Actual Foot Clearance

2.3 Arduino Microcontroller

The Arduino is a simple yet powerful microcontroller board. The microcontroller that was used in this research is an Arduino based ArduIMU V2 Flat Microcontroller module. From the experiment and the analysis, the ArduIMU V2 Flat is easy to be programmed, simple to be configured, and the more stable output data. This microcontroller consists of ATmega328 and a MEMS based Inertial Measurement Unit sensor. The MEMS based IMU from Analog Device (consist of 3 axis accelerometer) and ST Microelectronic (consist of single and dual axis gyroscope) is integrated with the board. This microcontroller was programmed using C language through Arduino platform software. Here, the reading from the ultrasonic sensor will be processed by microcontroller and transferred to the LabVIEW software for data visualization through wireless communication. An error correction algorithm for the ultrasonic sensor readings was included in LabVIEW software. Fig 4 shows the ArduIMU V2 Flat structure.

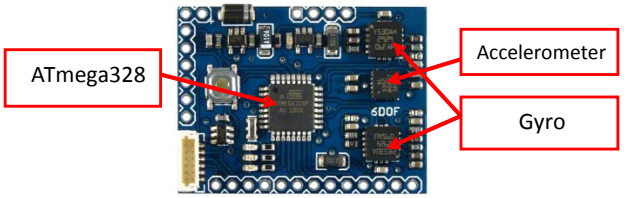


Fig 4. ArduIMU V2 Flat

2.4 XBee Transceiver (2.4 GHz IEEE 802.15.4)

In this research, the wireless communication between the hardware and the software was applied to ensure the connectivity will not disturb movement and ensure the user feels comfortable. Due to that characteristic, wireless technology can be used during daily activity without hassle for enabling the in-situ measurement. Here, XBee 1mW Wire Antenna Module was used as transmitters and XBee Starter Kit from Cytron Technologies Sdn. Bhd. as receiver. This wireless communication between both XBee modules can be established up to 30 m indoor or urban range and up to 100m for outdoor or line-of-sight range. So, this is the one of the unique features of our technology as compared to the other technology that used wired connectivity. Fig 5 shows the XBee 1mW Wire Antenna and its Starter Kit.

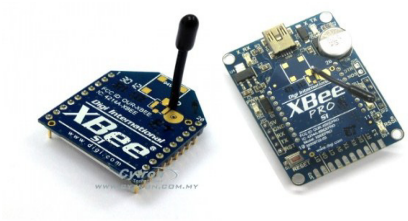


Fig 5. (Left) The X-Bee 1m Wire Antenna, Transmitter;
(Right) The X-Bee Starter Kit, Receiver

2.5 Power

The entire system was powered up by rechargeable Lithium Polymer (LiPO) battery. The 7.4V Lithium Polymer 1000mAh battery was used to power up the Arduino controller for more than 4 hours operation. Fig 6 shows the physical structure of the 7.4V Lithium Polymer battery with 1000mAh. The battery specification is shown in Table 2.

Fig 6. 1000mAh 7.4 V Lithium Polymer battery

Table 2. Specification of Lithium Polymer Battery

Specification/ Battery	Lithium Polymer (E SHORE TECHNOLOGIES, 2012)
Voltage	7.4V
Capacity	1000mAh
Time Period	More than 4 hours
Weight	62g
Size	70 x 35 x 13 mm
Type	Lithium Polymer
Manufacturer	Turnigy, UK

2.6 Development Board

The rehabilitation monitoring development board has been already preassembled with Arduino compatible ATmega328 microcontroller and IMU known as ArduIMU V2. The limitation in our PCB design is there only capable to produce single layer of the circuit. The dimension of the in-house PCB development board is 6cm x 8.4cm x 0.2cm like shown in Fig 7.

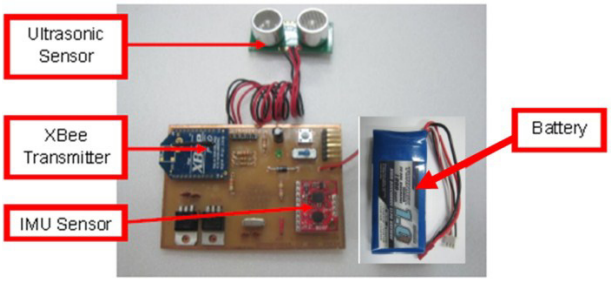


Fig 7. Microcontroller Development Board

2.7 Measurement Setup

In this research, the development of the rehabilitation monitoring system involves LabVIEW 2010 Software Development Kit. The LabVIEW 2010 has been chosen because of its proven performance, industry standard and also because it‘s accepted worldwide. In detail, the LabVIEW 2010 is a graphical programming language where the user sets the instructions for program execution using the dataflow execution order block diagram while all the user interface are built up using the graphical representation of the function at the front panel section. The experimental setup for verification of ultrasonic sensor reading as shown in Fig 8 is to compare the SRF05 ultrasonic sensor

reading with the reference distance. It is important to confirm that SRF05 give the accurate distance reading before real implementation in the shoe integrated system.

Fig 8. Ultrasonic Sensor Signal Verification

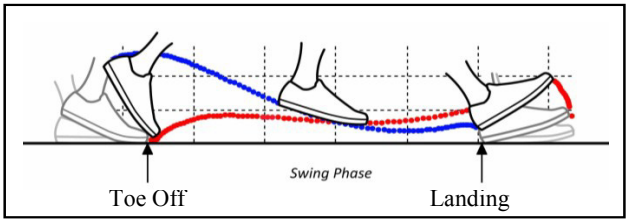
3. Result

The graphical human movement pattern of subject during walking is shown in Fig 9. The graph shows the several cycle of gait pattern including the gait phase such as MFC, toe off and landing phase. However, the measurement still incorrect due to the offset start reading point and the angle of the feet during walking. The ultrasonic system gives the direct distance reading instead of the foot clearance reading. But the successful display of the human movement pattern of subject during walking showing the applicability of the system.

3.1 Analysis of Ultrasonic System

The captured human movement pattern and data collected from ultrasonic system is a concrete proving that it can be used for rehabilitation monitoring measurement. The illustration of human movement pattern for walking as compared to the human movement graph pattern is shown in Fig 9. Fig 10 shows the similarity of the gait pattern captured by the system and the gait pattern captured by [10].

(a)



(b)

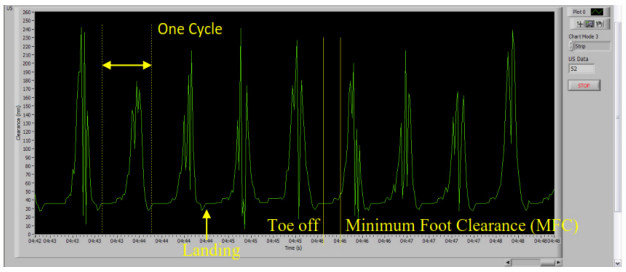


Fig 9. (a) Human Movement Pattern for Walking Subject;
(b) Human Movement Graph Pattern.

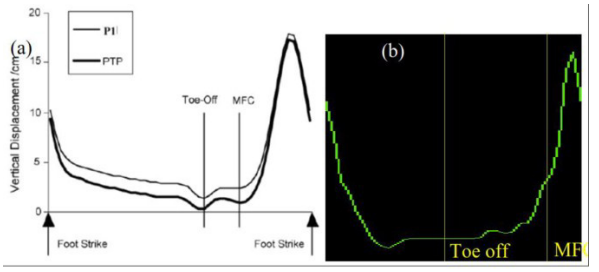


Fig 10. (a) Gait Pattern by [11] and
(b) Gait Pattern by Rehabilitation Monitoring System

However, the Fig 10 (b) is slightly different with Fig 10 (a). The difference is due to the subject origin as in this research involves the Asian people and research in [11] involves the American people. Normally the American people are taller than Asian people. Hence the gait cycle of American people is larger than the gait cycle of Asian people. Thus, this human movement pattern by Rehabilitation Monitoring System can be used to extract the gait information.

3.2 Analysis of IMU System

The IMU analysis system is the combination of hardware development board with LabVIEW software. Fig 11 shows the gait pattern for walking subject using IMU system. This system is used to study the movement pattern from the IMU sensor measurement and compared the movement pattern captured during walking with the gait pattern from ultrasonic system. Similarly with the analysis of ultrasonic system, this system also analyzes the human movement pattern based on foot clearance but the data displayed in degree. The hardware development board system is fixed on top of attachment unit and attached to the subject shoes. The subject is walked during their daily activity. This experiment is conducted out of the laboratory to ensure this system can be used in real-life. The gait pattern in Fig 11 is carefully analyzed and observed. The IMU system is acceptable to be used in gait analysis measurement because of the collected gait pattern is almost similar to the previous study in [12] as shown in Fig 12.

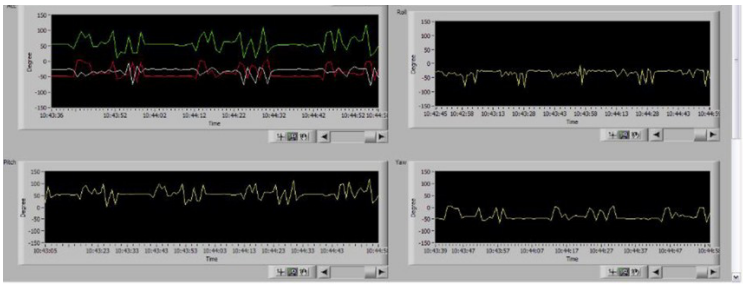


Fig 11. Pattern for Walking Subject using IMU System

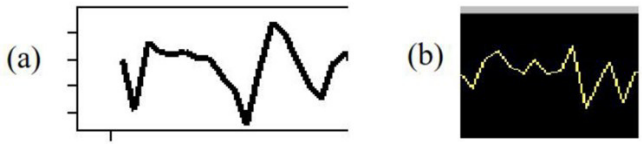


Fig 12. (a) Gait Acceleration Signal [12] and
(b) Gait Signal by IMU System

4. Conclusion

In this research, a complete system called wireless rehabilitation monitoring in real-time is successfully developed and analyzed. The Development of Shoe Attachment Unit for Rehabilitation Monitoring comes with the custom design includes ultrasonic sensor, IMU, Arduino microcontroller, XBee signal transmission, power supply unit and LabVIEW software. The novelties of this research are wearable shoe attachment for wireless monitoring of foot clearance during walking or while performing the daily routine in the house or outside of the house. The medical specialist also able to monitoring the elderly gait, weakness identification and injury prevention for their patient. This system has high potential to be market especially for rehabilitation centers, sports centers, health centers, hospitals, research organizations, and the elderly. Successfully complete the system with the presented results, this system has proven that a Development of Shoe Attachment Unit for Rehabilitation Monitoring is realizable and practical.

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